DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

May 8, 2012

MEMORANDUM FOR: T. J. Dwyer, Technical Director

COPIES: Board Members

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SUBJECT: Documented Safety Analysis and Post-Seismic Accident Consequences, Plutonium Facility, Los Alamos National Laboratory

This report documents a review by the staff of the Defense Nuclear Facilities Safety Board (Board) of the 2011 Documented Safety Analysis (DSA) for the Plutonium Facility (PF-4) at Los Alamos National Laboratory (LANL). The review included assessment of the 2011 DSA update and revisions, the safety evaluation report developed by the National Nuclear Security Administration's (NNSA) Los Alamos Site Office (LASO) to approve the DSA, as well as an on-site review performed during the week of March 19, 2012. Follow-up discussions with LANL and NNSA personnel occurred on April 26, 2012. Staff members F. Bamdad, B. Broderick, T. Chapman, T. Davis, C. March, J. Pasko, and R. Verhaagen participated in elements of the review.

Background. In December 2008, the LASO manager approved the first major update to PF-4's safety basis since 1996. The 2008 DSA postulated a seismically-induced fire scenario for PF-4 and reported a mitigated offsite dose consequence of greater than two thousand rem total effective dose equivalent (TEDE) for this event. As a result of this large mitigated offsite consequence, the Board issued Recommendation 2009-2, *Los Alamos National Laboratory Plutonium Facility Seismic Safety*. In this Recommendation, the Board urged NNSA and LANL to execute both immediate and long-term actions to reduce the risk posed by a seismic event at PF-4.

In response to the Board's Recommendation, NNSA and LANL personnel: (1) executed a series of near-term compensatory measures designed to reduce the risk of a seismically-induced fire at PF-4; (2) identified a number of new safety-class engineered controls, including seismic cutoff switches for electrical power, seismically qualified material storage safes, and fire-rated material storage containers; and (3) developed a Project Execution Plan for longer-term upgrades to enable the confinement ventilation and fire suppression systems to perform safety-class functions following a Performance Category (PC)-3 seismic event.

In addition to physically upgrading the building structure and implementing new safety-class engineered controls, laboratory personnel completely reanalyzed the seismically-induced fire scenario in the 2011 DSA. The new analysis in the 2011 DSA concludes that the mitigated offsite dose consequence for the seismically-induced fire scenario is 23 rem TEDE, which is less

than the Department of Energy (DOE) Evaluation Guideline of 25 rem TEDE. This analyzed offsite dose consequence is two orders of magnitude lower than the mitigated offsite dose consequence calculated by the 2008 DSA. The roughly 100-fold decrease results from changes to four accident analysis parameters: the quantity of material at risk, airborne release fractions, respirable fractions, and leak path factor (LPF). Revision 1.0 of the 2011 DSA was approved by LASO on October 13, 2011, and the DSA and its associated technical safety requirements (TSR) are currently scheduled to be implemented by June 25, 2012.

Justification for Continued Operations. Subsequent to the Recommendation and efforts by LANL that considerably reduced offsite dose consequences, LANL engineers evaluated the impact of the most recent update to the site's Probabilistic Seismic Hazard Analysis (PSHA). These PSHAs are conducted approximately every ten years to update the threats from earthquakes. This latest PSHA predicted an increase in the magnitude of seismic ground motions, leading to severe seismic accident scenarios, such as facility collapse, becoming more credible. A Justification for Continued Operations (JCO) that addressed these new severe seismic accident scenarios was approved by NNSA in July 2011. This JCO supplements the DSA as the governing safety basis for the facility. It will serve as the safety basis of record until superseded by implementation of the 2011 DSA.

In response to the discovery that critical structural elements of PF-4 were seismically vulnerable, NNSA and LANL personnel initiated and successfully completed physical upgrades that addressed all known structural vulnerabilities. (However, further seismic analysis is in progress that could reveal additional vulnerabilities.)

Path Forward. Once implementation of the 2011 DSA is independently verified, LANL personnel intend to retire the seismic JCO. Consequently, the Board's staff carefully reviewed the four accident analysis parameters that serve as the underpinning of the 2011 DSA: the quantity of material at risk, airborne release fractions, respirable fractions, and LPF. The Board's staff noted a substantial number of issues, discussed below, that challenge the technical basis for these parameters and, consequently, for the 23 rem TEDE mitigated offsite dose consequence reported in the 2011 DSA.

Leak Path Factor Analysis. The 2008 DSA postulated that a seismically-induced fire would engulf the entire laboratory floor of PF-4 and generate sufficient thermal energy to drive a large fraction of aerosolized material out of the building resulting in a LPF of 40 percent. The 2011 DSA uses a 3 step approach to derive a new, lower LPF for the reanalyzed seismically-induced fire scenario. The first step analyzes historical data related to the number of fires reported following earthquakes in California and Alaska to develop a probabilistic argument that seismically-induced fires will be limited to some number of individual laboratory rooms rather than affecting the entire laboratory floor. The second step uses Consolidated Model of Fire and Smoke Transport (CFAST) software to model fires and develop thermal and material transport profiles as a function of time for selected laboratory rooms where seismically-induced fires were assumed to be present. The final step uses Methods for Estimation of Leakages and Consequences of Releases (MELCOR) software to calculate the fraction of material released from the building (i.e., the LPF). The 2011 DSA credits the safety-class building structure to maintain its confinement integrity during a PC-3 seismic event and to mitigate releases from seismically-induced accidents. The DSA relies on the passive confinement of PF-4 structure to

mitigate the material release and associated offsite dose consequence from a seismically-induced fire scenario. The staff identified a number of issues, described below, that challenge the technical validity and defensibility of the LPF values used in the 2011 DSA. A number of these LPF-related issues are similar to concerns communicated by the Board in a letter to NNSA dated May 30, 2008.

LPF Value for the Spill Contribution to the Seismically-Induced Fire—The MELCOR analysis that generated the LPF values used in the 2011 DSA included a number of parametric runs. For a given parametric run, a number of individual laboratory rooms were assumed to contain seismically-induced fires and a given amount of material at risk (MAR) was allocated to each fire. Additionally, rooms without fires (non-fire rooms) were also modeled with a given amount of MAR which was spilled. The MELCOR analysis that generated the bounding LPF value (18 percent) used in the 2011 DSA modeled an integrated seismic accident scenario that involved releases due to both seismically-induced fires in two fire rooms and seismically-induced spills in fourteen non-fire rooms.

The LPFs generated using MELCOR are ultimately used in the DSA accident analysis to calculate dose consequences. For the seismically-induced fire scenario, the DSA accident analysis assumes that material is spilled and then becomes involved in a fire. This accident analysis evaluates the dose contributions from the spill release and the fire release separately and then combines the results to obtain the total mitigated offsite consequence of 23 rem TEDE. Consequence calculations for the fire component of the release use the 18 percent LPF calculated by the MELCOR model discussed above. However, consequence calculations for the spill component of the release use an LPF of only 5 percent. Given that the 18 percent LPF value was calculated in MELCOR for an integrated scenario that included both spill and fire releases, it is not technically justifiable to use a separate, lower LPF value for the spill contribution. If the appropriate LPF value of 18 percent were applied to the spill component of the release, the Board's staff estimates the dose contribution of the spill would increase by a factor of 3.6, and the overall offsite dose consequence would increase by roughly 80 percent.

Implicit Crediting of Laboratory Walls—The walls of PF-4's laboratory rooms consist of gypsum board panels that are mechanically fastened to metal framing. These laboratory walls have not been credited as safety-class or safety-significant design features in the PF-4 DSA and have not been evaluated to maintain their integrity in a PC-3 seismic event. However, the CFAST and MELCOR models for PF-4 rely on an assumption that laboratory walls will remain intact after an earthquake. By assuming the laboratory walls are intact, the amount of oxygen available to feed a room fire is constrained and the overall size and heat release rate from the fire are limited. Additionally, assuming laboratory walls are intact significantly limits the surface area of flow paths through which the aerosolized source term can escape from fire rooms into the corridor and ultimately into the environment. Inappropriately relying on laboratory walls to perform functions that they are not credited or qualified to perform is a non-conservative assumption that potentially underestimates the LPF and overall offsite dose consequence.

Quantity of Combustibles Assumed for Some Fire Rooms—Laboratory rooms that process heat source plutonium-238 (HS-Pu) materials include fixed and mobile polymethyl methacrylate (PMMA) shielding to reduce the neutron dose to glovebox workers. The PMMA shielding is

combustible and represents a large potential source of fuel to feed HS-Pu laboratory room fires. Room fire characteristics calculated by CFAST and input into MELCOR are strongly influenced by the quantity of combustible materials present to fuel the fire. The CFAST modeling of HS-Pu laboratory room fires assumes that the amount of PMMA is limited to the fixed PMMA shielding on only four gloveboxes and does not account for the significant amount of mobile PMMA shielding present. There are more than four gloveboxes in one HS-Pu room, and all have the potential for becoming involved in a fire. Therefore, postulating an HS-Pu room fire that involves only combustible fuel from the fixed PMMA shielding of four gloveboxes is also a non-conservative assumption that leads to an underestimation of LPF values and overall offsite dose consequences.

Respirable Fraction for Finely Divided Heat Source Plutonium Powder. Unlike the 2008 DSA, the accident analysis for the seismically-induced fire scenario in the 2011 DSA disaggregates MAR to account for the wide variability in dose conversion factors and dispersibility represented by the diverse materials present in PF-4. Under this new approach, finely divided HS-Pu powder is one of the most important contributors to the overall offsite dose consequence. HS-Pu is enriched in the Pu-238 isotope, which has a high specific activity and dose conversion factor. Mechanical processing creates a very finely divided powder with an average particle size of approximately 1 micron geometric diameter (or about 3.5 microns aerodynamic equivalent diameter [AED]), which makes it highly dispersible and respirable under accident conditions. DOE Handbook 3010, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, defines respirable fraction (RF) as the fraction of material that has an AED of 10 microns or less. The DSA assumes an RF of 0.3 for finely divided HS-Pu powder that is released in a seismically-induced spill and an RF of 0.1 for finely divided HS-Pu that is released in a fire.

The RF value of 0.3 assumed for finely divided HS-Pu powder spilled in a seismic event uses the bounding experimental RF value, derived from unrepresentative test materials, reported in DOE Handbook 3010. However, this value may not be appropriate for finely divided HS-Pu where the source material is initially all in the respirable particle size regime. This is reflected in Section 3.4.3 of the 2011 DSA in the accident analysis for a container handling event. This scenario analyzes the consequences of dropping and breaching a HS-Pu container. This DSA evaluation states that if the material involved in the accident is finely divided HS-Pu powder, then an RF of 1.0 must be assumed.

LANL analysts derived the assumed fire RF of 0.1 by taking the bounding experimental value of 0.01 from DOE Handbook 3010, which is based on experiments using test materials that are not representative of finely-divided HS-Pu powder, and increasing it by an arbitrary factor of 10. The analysts indicated that the factor of 10 is intended to account for the difference between finely divided HS-Pu powder with an average particle size of about 3.5 microns AED and the much coarser test materials with particle sizes of 15–150 microns AED that were used in the experiments reported in the Handbook. The DSA notes that the assumed RF for finely divided HS-Pu powder in fires was only increased to 0.1 rather than to 1.0 as in previous versions of the analysis because powders with small initial particle sizes tend to agglomerate into larger and less respirable particles.

To support this agglomeration argument, the DSA references a white paper submitted by an author of DOE Handbook 3010 that discusses agglomeration phenomena observed in experiments performed using finely divided uranium oxide. However, the Pu-238 constituent of HS-Pu has properties and characteristics that are significantly different than uranium oxide. Pu-238 is an intense alpha emitter with a relatively short half-life of 88 years. As a result of this high specific alpha activity, Pu-238 oxide material exhibits significant self-heating (hence its use as a heat source) that tends to drive off moisture and limit water adsorption. Self-heating of Pu-238 oxide would tend to cause finely divided HS-Pu powder to resist particle agglomeration. The white paper referenced in the DSA also assumes the presence of conditions that do not exist in the facility, such as seismically-qualified support stands for HS-Pu gloveboxes. Since HS-Pu behaves differently than uranium oxide and exhibits characteristics that would resist significant particle agglomeration, the RF value of 0.1 assumed in the DSA cannot be technically justified.

Relevant experimental data using representative test materials is limited and the information that is available in the technical literature on agglomeration phenomenology for finely divided HS-Pu provides contradictory conclusions. There are studies and reports that refer to agglomeration of HS-Pu in moist environments, such as deactivated gloveboxes and hot cells; however, such conditions do not exist at PF-4 due to rigorous climate control and quality requirements that prohibit the introduction of considerable amounts of moisture into PF-4 gloveboxes.

The staff believes that the RF values assumed in the DSA for finely divided HS-Pu powder are non-conservative for both spill and fire releases. If the seismically-induced fire analysis used the technically defensible RF value of 1.0 (for both spill and fire components of the accident), the Board's staff estimates the overall mitigated offsite dose consequence would increase by a factor of 3.3.

Lack of Independent Review for DSA Input Documents. The accident analysis for the seismically-induced fire scenario references several supporting calculations and analyses that supply important quantitative inputs to the DSA. The quality and fidelity of the inputs from these supporting documents affects the quality and fidelity of the analysis in the DSA. At LANL, procedure AP-341-605, *Calculations,* specifies the institutional requirements governing the preparation and review of calculations and analyses that provide important quantitative inputs to safety basis documents such as DSAs. AP-341-605 requires that all safety basis input calculations and analyses be checked and independently reviewed by personnel who were not involved with the development of the calculation or analysis. The staff identified multiple analyses that provide quantitative inputs to the safety basis and are explicitly referenced by the DSA that did not comply with the independent review requirement of AP-341-605. The examples summarized below echo quality assurance issues for DSA input documents that were communicated by the Board in a letter dated May 30, 2008:

- Reference 3-65, LA-UR-11-01857, *Modeling the Number of Ignitions Following an Earthquake: Developing Prediction Limits for Overdispersed Count Data,* documents statistical analysis on historical data deriving the probability that a given number of laboratory room fires will occur after a PC-3 seismic event. Results from

this analysis are used as quantitative inputs to the DSA. Site analysts did not apply the required AP-341-605 review process to LA-UR-11-01857.

- Reference 3-112, Memo SB-PF:10-007, *Statistical Evaluation of Damage Ratio Data*, documents statistical analysis on fire test data for two safety-class containers. Results from this memo were used to support a credited damage ratio of 0.01 for the safety-class containers in the DSA. Site analysts did not apply the required AP-341-605 review process to memo SB-PF:10-007.

Credibility of a Seismically-Induced Fire in the Basement. The 2011 DSA assumes that a seismically-induced fire is not credible in the PF-4 basement. However, the basement houses combustible material, high voltage electrical switchgear that is not seismically qualified, and activation of the seismic switches does not remove the source of power to the switchgear. The analysis in the DSA does not consider these factors when concluding that a seismically induced fire is not credible. There is a significant amount of MAR stored in the facility basement that could provide an important contribution to the offsite consequence if it were involved in a seismically-induced fire. Furthermore, the leak path factor for other postulated basement fires involving flammable liquids is a relatively high value of 30 percent. The consequences from a fire in the basement should either be accounted for or additional technical justification should be provided to defend the assumption that a seismically-induced fire in the facility basement is not credible.

Probabilistic Fire Analysis. As part of the DSA development, LANL personnel performed a probabilistic analysis of a fire at PF-4 following a PC-3 earthquake. Based on this analysis, the DSA states that one random (or "probabilistic") fire will occur after a PC-3 seismic event. The DSA also postulates three additional "deterministic" fires to account for operations involving molten plutonium metal that could significantly increase the likelihood of initiating a fire. The probabilistic analysis is based on data in Reference 3-65, LA-UR-11-01857, *Modeling the Number of Ignitions Following an Earthquake: Developing Prediction Limits for Overdispersed Count Data,* related to fires following earthquakes in Alaska and California. This data is used to derive the likelihood of a fire as a function of facility square footage and peak ground acceleration of the seismic event. The staff identified the following issues with the use of this probabilistic analysis:

- Site analysts did not follow the applicable LANL review procedure to validate the probabilistic analysis.

- The source data does not account for multiple fires in one structure.

- The source data does not reflect the seismic upgrades that may have been applied to some structures in California to comply with building code requirements.

- The data set is limited, includes significant reports from residential areas and may not be representative of the likelihood of a fire in a facility like PF-4.

- Based on the stated purpose of the data set (to "allow fire departments and emergency planners to quickly estimate the number of ignitions they may be confronted with..."), it does not appear appropriate for predicting the likelihood of a fire in an individual unique facility like PF-4. The authors note that "there is considerable uncertainty on estimates derived using these relations" to estimate ignitions per million square feet of floor space.

Additionally, site analysts did not effectively use the guidance provided by the DOE Risk Assessment Technical Expert Working Group that was established in response to the Board Recommendation 2009-1, *Risk Assessment Methodologies at Defense Nuclear Facilities*, to assist in the appropriate preparation of quantitative risk assessments.

Conclusion. Based on the Board's staff review, the DSA utilizes several non-conservative parameters and methodologies in deriving the 23 rem TEDE mitigated off-site dose consequence from this scenario. Use of appropriately conservative parameters and methodologies would significantly increase the dose consequence for this postulated accident, to 100 rem TEDE or greater, and compel the application of necessary safety controls.